

## **CHBE 501, Transport Phenomena, Fall 2014**

Meeting: 10:00 AM MWF; Mechanical Lab 254

Instructor: George J. Hirasaki, [gjh@rice.edu](mailto:gjh@rice.edu), ext 5416

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Textbooks: Aris, *Vectors, Tensors and the Basic Equations of Fluid Mechanics*

Bird, Stewart, and Lightfoot, *Transport Phenomena*

- Computing languages
  - MATLAB
  - FORTRAN
- Grading: Assigned problems and examinations; each exam, (at least one), will be 25% of the total grade.
- Each assigned problem will have due date, usually the first class periods after assignment. Solution will be distributed. Students will self-grade on 0 – 100 scale.
- Problems turned in next class period after due date or reworked will be credited 80% of maximum score on reworked portion. Self-grade and put original and reworked scores on paper and hand-in. Teaching Assistant will audit grading and post in OwlSpace score-sheet.
- Collaborative discussions are encouraged on assigned problems only if you have difficulty. However, each student should turn in only their own work.
- Some assignments will be team projects.

Assistance: If you have difficulty with lecture material or assigned problem, first discuss with another student. If two or more students cannot resolve problem, see Professor Hirasaki or teaching assistant.

Misc.: Please point out error in notes and suggestions for improvements are welcome.

## **CHBE 501 Transport Phenomena**

### **1. Introduction**

**Prerequisites and text books**  
**Scalar, vector and tensor fields**  
**Curves, surfaces, and volumes**  
**Coordinate systems**  
**Continuum approximation**  
**Densities, potential gradients, and fluxes**

### **2. Cartesian Vectors and Tensors: Their Algebra**

**Definition of a vector**  
**Examples of vectors**  
**Scalar multiplication**  
**Addition of vectors - Coplanar vectors**

- Unit vectors
- A basis of non-coplanar vectors
- Scalar product - Orthogonality
- Directional cosines for coordinate transformation
- Vector product
- Velocity due to rigid body rotations
- Triple scalar products
- Triple vector products
- Second order tensors
- Examples of second order tensors
- Scalar multiplication and addition
- Contraction and multiplication
- The vector of a antisymmetric tensor
- Canonical form of a symmetric tensor

### **3. Cartesian Vectors and Tensors: Their Calculus**

- Tensor functions of time-like variable
- Curves in space
- Line integrals
- Surface integrals
- Volume integrals
- Change of variables with multiple integrals
- Vector fields
- The vector operator  $\nabla$  - gradient of a scalar
- The divergence of a vector field
- The curl of a vector field
- Green's theorem and some of its variants
- Stokes' theorem
- The classification and representation of vector fields
- Irrotational vector fields
- Solenoidal vector fields
- Helmholtz' representation
- Vector and scalar potential

### **4. The Kinematics of Fluid Motion**

- Particle paths and material derivatives
- Streamlines
- Streaklines
- Dilatation
- Reynolds' transport theorem
- Conservation of mass and the equation of continuity
- Deformation and rate of strain
- Physical interpretation of the deformation tensor
- Principal axis of deformation
- Vorticity, vortex lines, and tubes

### **5. Stress in Fluids**

- Cauchy's stress principle and the conservation of momentum
- The stress tensor
- The symmetry of the stress tensor
- Hydrostatic pressure
- Principal axes of stress and the notion of isotropy
- The Stokesian fluid
- Constitutive equations of the Stokesian fluid
- The Newtonian fluid Interpretation of the constants

## **6. Equations of Motion and Energy in Cartesian Coordinates**

- Equations of motion of a Newtonian fluid
- The Reynolds number
- Dissipation of energy by viscous forces
- The energy equation
- The effect of compressibility
- Resume of the development of the equations
- Special cases of the equations
- Boundary conditions
- Scaling, dimensional analysis, and similarity
- Bernoulli theorems

## **7. Solution of the Partial Differential Equations**

- Classes of partial differential equations
- Systems described by diffusion equation
- Greens function, convolution, and superposition
- Green's function for the diffusion equation
- Fourier transform method
- Convective-diffusion equation
- Similarity transformation
- Complex potential for irrotational flow
- Solution of hyperbolic systems

## **8. Laminar Flows with Dependence on One Dimension**

- Couette flow
- Poiseuille flow
- Steady film flow down inclined plane
- Unsteady viscous flow

## **9. Multidimensional Laminar Flows**

- Lubrication and film flow
- Laminar boundary layer
- Creeping flow in wedge
- Flow around particle

## **10. Flow through Porous Media**

## **11. Flow with Free Surface**

**Boundary conditions at a fluid-fluid interface**  
**Static gravity - capillary equilibrium**  
**Dynamics of viscous, capillary, gravity flow**  
**Film drainage and deposition with Laplace pressure**

**12. Numerical Simulation (if time allows)**

**The stream function - vorticity method**  
**Finite difference approximation**  
**Solution of linear equations**  
**FORTTRAN on Owlnet**  
**Transients and finite Reynolds numbers**  
**Calculation of pressure and stress**  
**Cylindrical-polar coordinates**  
**Flow past cylinder**